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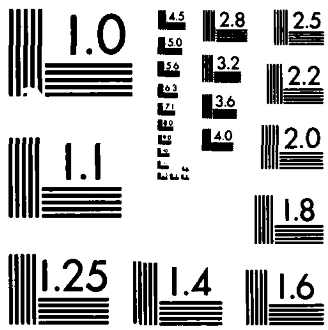
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NRL Memorandum Report 5622

Optical/IR Characteristics of Alkali Halide Aerosol Clouds Over the Ocean

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Atmospheric Physics Branch
Space Science Division

September 5, 1985

NAVAL RESEARCH LABORATORY
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Artificial fogs grown on hygroscopic alkali halide (Salty Dog) nuclei were produced over the North Atlantic Ocean using 180 pound pyrotechnic generators deployed from the USNS LYNCH. Canopy Clouds were produced when heat from the burn carried the material aloft, if the relative wind at the ship was small during the burn. Surface clouds were formed if the burn took place while the ship was in motion relative to the surrounding air. When the wind speed was less than the ship's speed, it was possible to re-enter the surface clouds and make measurements on the size distribution of the aerosol particles.

Shipboard instrumentation measured the particle size distributions and light scattering characteristics of those clouds which the ship could enter. The agreement between measured extinction and that calculated from particle size data was good. Only remote sensing could be used for canopy clouds, and sun photometer measurements of the light extinction by the canopy clouds were consistent with theoretical estimates of changing particle size

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distributions. The ship also carried instrumentation to monitor ship position, speed and direction, sea surface and air temperatures at various altitudes, radiosonde equipment, and the NRL eye safe lidar. Originator supplied keywords include:

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OPTICAL/IR CHARACTERISTICS OF ALKALI HALIDE AEROSOL CLOUDS OVER THE OCEAN

I INTRODUCTION

This report is a description of field tests done at sea with a type of artificial aerosol which has the potential to provide large scale screening for Naval applications. This concept depends on the interaction of small hygroscopic alkali halide particles with natural water vapor present in the marine boundary layer. The result of this process is increased scattering of the electromagnetic waves propagating through the atmosphere due to the increase in size of individual aerosol particles by the addition of water molecules already existing in the atmosphere. The larger the mean size of the resultant droplet concentration, the larger will be the wavelengths affected by the scattering. It is therefore a method to utilize the ambient water vapor resident in the marine boundary layer to extend the extinction into the longer infrared wavelengths without having to produce and dispense such large scatterers directly. Such a material with the utilization of ambient water vapor would produce savings in logistics.

The size of these hygroscopic droplets is directly controlled by the available water vapor supply, that is, by the ambient relative humidity about the particle. The higher the relative humidity, the larger the droplet will grow. As the growing droplets use the water from the ambient vapor supply, the surrounding relative humidity is lowered, and their maximum growth is correspondingly limited. However, in the marine environment as water molecules are added to the droplets, the natural process of transferring water molecules from the sea surface into the atmosphere through eddy diffusion will be resupplying the depleted supply of water vapor. The rate at which these processes proceed is important but eventually there will be a resupply of the water molecules in the form of vapor to the air surrounding the now larger droplets. The growth and long term stability properties of the alkali halide aerosol appear to be consistent with respect to time and these droplets do not have negative long term health effects as do some other screening smokes. Alkali halide materials therefore, seem to be a promising material for producing a large safe, long lasting screen.

Interactions of the alkali halide aerosol with meteorological processes of the marine boundary layer become very important when producing large scale, long term screens. The major meteorological processes which can reduce the screening effect of a alkali halide layer are:

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1) Turbulent mixing of the aerosol which reduces the concentration of the droplets.

2) Transport of the aerosol droplets to areas where the relative humidity is low and where the absorbed water is lost by evaporation.

3) The advection of the screening layer away from the area where the screening is desired.

4) The formation of particles and droplets so large they fall out under the force of gravity.

Although the greatest potential use of alkali halide aerosol is as a large area screen which has useful lifetimes measured in hours rather than minutes, it has yet to be shown that the long term behavior of these aerosols in the marine boundary layer is as predicted. Some of the important physical processes which operate on hygroscopic aerosol in the marine boundary layer are:

1) Size changes of individual particles as a function of the ambient relative humidity.

2) Gravitational fallout of the largest droplets.

3) Dispersion of the aerosol by turbulent diffusion processes in the marine boundary layer.

4) Advection of the aerosol.

The utilization of artificial aerosol introduced into the marine boundary layer in an effort to produce screening effects must take into account these processes. These concepts were tested at sea in March 1983 in the North Atlantic ocean by a series of experimental pyrotechnic burns whereby methods were devised by which a plume of hygroscopic aerosol produced in the open ocean by the ship operating alone could be observed by the same vessel equipped with specialized aerosol sizing and optical scattering instruments.

II EXPERIMENT

During cruise NRL #705-83 aboard the USNS LYNCH, (T-Agor-7), personnel from NRL, NWC, PMTC, Calspan Corporation, and Argonne National Laboratory performed experiments from 11 March to 17 April 1983. The cruise track from Charleston, SC via Las Palmas, Canary Islands to Glasgow, Scotland is shown in figure 1. While there were several purposes for the cruise, the aspects presented in this report cover specifically the burning of ten pyrotechnical generators to produce clouds of alkali halide aerosol in the marine atmosphere and subsequent measurements to study the time history of these aerosol clouds. Artificial aerosol clouds were generated on three different days of the cruise and data during these periods of time are the subject of

this paper. The location of the experiments on 20, 23 and 30 of March 1983 are marked in figure 1.

The ship was equipped to support 180 pound pyrotechnic generators using CY85A, a "Salty Dog" pyrotechnic. This material developed by NWC, (Mathews & St. Amand, 1980), was an early alkali halide aerosol pyrotechnic which on ignition produces prodigious quantities of hygroscopic aerosol. When this aerosol is diffused into the boundary layer at relative humidities above 65%, it produces airborne water drops which scatter electromagnetic radiation.

The techniques of pyrotechnic construction whereby CY85A was gravity cast into large stainless steel drums, are discussed in the Appendix of Gathman et al. (1981). The pyrotechnic generator was supported by block and tackle on a stern davit of the ship and held in a horizontal position by two control lines, with the active part of the pyrotechnic facing away from the ship. As a safty precaution the burner was lowered below deck level before being electrically ignited. The production of aerosol by the device on board the stationary ship is shown in figure 2. Note that a protective covering was hung along the stern of the ship to guard against accidental damage to the paint of the ship by the pyrotechnic.

Instrument systems mounted on the bow, mast and on the top of an instrument shelter situated on deck forward of the bridge were used to provide characterization of the marine boundary layer during the experiments. Table I lists these instruments and the parameters measured. The measurements are divided into two classes:

1) Those which are essentially insitu measurements and require the ship to penetrate to the site where the sample is to be taken.

2) Remote sensing measurements of the vertical structure above the ship.

Difficulty was experienced in using the same ship to both generate the aerosol plume and to follow the plume downwind, penetrate it and to make insitu measurements within it. The maximum cruise speed of the ship is about 10 knots and thus wind speeds had to be substantially less than 10 knots in order for the ship to catch up with and penetrate the plume. Of course, when elevated clouds were produced by artificial means they could not be penetrated by the ship and only remote sensing methods were applicable to make measurements. An additional constraint on the operation was that the sky had to be relatively clear of natural clouds in order for the artificial plumes to be clearly observed.

III BACKGROUND METEOROLOGY AND OPTICS

Mesoscale meteorology during the obscuration experiments was important to the development of the obscuration layer and subsequent modification of the optical environment by the artificial aerosol introduced into the marine boundary layer. The data presented here was taken by several different investigators from laboratories of the U.S. Government and it's contractors, and is but a small subset of the total data taken during the cruise. The authors have limited the data presented here to that necessary for determining the meteorological situation about the ship during the three days of the test. Data used for the description of the marine boundary layer consisted of vertical soundings made with radiosondes, lidar and a sun photometer. These data together with shipboard observations of meteorological and optical parameters done insitu in the lower part of the marine boundary layer provided the background measurements for the experiments. These data are presented graphically with comments on the physical features which appeared during the experiment. The complete data are given in Gathman (1985), and included in the AAODL, DoD's atmospheric aerosol and optics data, for archivial purposes. The AAODL is a computerized collection of field data and documentation and is available to the user community under the authorization of the Army's PM smoke office and ASL. Table II gives the timing of the obscuration events discussed later on.

Temperature profile measurements are important to determine the stability of the marine atmospheric boundary layer into which the artificial aerosols are introduced. Table III shows the temperature measurements averaged over the period of the tests for the three experiment days. The six temperature probes were located on the ship as described in the table. Each instrument is accurate to within 0.2 degree C, thus the difference between the various sensors has to do with their location, the temperature gradient over the sea surface, and the distortion of the temperature field caused by the presence of the ship itself. One air temperature instrument was mounted just above the instrument shelter at approximately 8 meters above the water. The shelter was positioned at deck level just forward of the bridge on the ship. This measurement is indicative of the air temperature on the ship deck and because of ship effects deviates from the temperature of the air away from the ship. The variable labeled "deck temperature" in the table was the dry bulb temperature measurement obtained with a sling psychrometer at the upwind point of the bow and represents the true air temperatures over water at deck level. The temperatures obtained by thermometers fastened to the mast at the levels of 20m, 14m and 7m respectfully and are representative of the true temperatures away from the ship in that they are located on the mast away from surface influences. The temperature of bucket samples of sea water is assumed to be the surface sea water temperature.

The data in table III indicate that the water temperature is approximately 1 degree C warmer than the air above it. If

this data were plotted versus height above the sea surface it would show a definite cooling with altitude, (except for the anomalous measurement made on top of the instrument shelter). This temperature profile has a faster temperature decrease with altitude than the lapse rate and thus indicates thermal instability at the lower sea surface boundary during these particular tests.

Because the atmosphere was not thermally stable, the heat produced by the burning process caused the plumes to rise without impediment throughout the boundary layer as they were generated. Plume rise could be reduced in practice by heading the ship so that the relative wind caused sufficient entrainment and cooling to stop the convective actions on the plume.

The growth of hygroscopic aerosol particles is most sensitive to the relative humidity in the boundary layer. Hoppel and Frick (1982) describe the hygroscopicity of aerosol from a similar type of pyrotechnic in terms of a nondimensional parameter B_o defined as:

$$B_o = \rho_o \eta_o / \rho_w \quad (1)$$

where η_o is the mass increase coefficient for an infinitely dilute solution and ρ_o and ρ_w are the densities of the dry particle and water respectively. From experiments in a large 500 cubic meter chamber, a value of B_o for the pyrotechnic CY85A and similar aerosols was found to be between 0.3 and 0.4.

Given that the hygroscopicity, B_o, of the artificially produced aerosols was of this magnitude, we may then obtain the dependence of the equilibrium particle size on relative humidity for various dry sizes of the particles. Figure 3 is a plot of this relationship from the theoretical considerations of droplet growth. From these relationships we can estimate the size distribution of the artificial aerosol at near saturation values of relative humidity.

These tests show that for dry sizes of $r > 0.03$ micrometers, the relationship between swelling factor and relative humidity is almost independent of the dry particle size and thus can be approximated by a single function. This is appropriate for the pyrotechnic materials used here since those same chamber experiments indicated that most of the aerosols are produced at dry sizes above this minimum value.

However, at ambient relative humidity between 55% and 75%, the history of relative humidity is important in determining the actual size of the droplet. The experimental results of Hanley & Mack (1980), reproduced in Figure 4, show a hysteresis like behaviour in the swelling factor of individual droplets with respect to relative humidity. At relative humidities above 75%, the theoretical curves are valid.

The mean relative humidity measurements expressed in units of percent for the experiment days are shown in Table IV. Both a cooled mirror dewpoint hygrometer and a sling psychrometer were used to obtain these measurements. The dewpoint hygrometer was located on top of the instrument shelter giving data which tended to be slightly lower in value than measurements taken at the rail and is believed to be an effect of the boundary environment of the ship. These relative humidity data when compared with the swelling factor plot of figure 3 or 4, show that the lower boundary layer was not a region in which to expect dramatic screening effects.

The vertical structure of the meteorological parameters is important as these parameters affect the rise, size, dispersal and optical properties of the cloud at different altitudes. The relative humidity profiles from radiosonde data taken at times just before or soon after the experiment are plotted in Figure 5. Although the altitude levels at which the radiosonde sends its data are widely separated, the flights show the general trend of increasing relative humidity with height throughout the boundary layer.

On the upper part of the plots is seen a hatched area denoting the range of altitude at which the shipboard lidar (Hooper, 1984) located the bases of scattered natural clouds during the evening hours which bracketed the dates of the experiment.

Figure 6 shows the virtual potential temperatures obtained from the radiosonde flights and indicate the stability of the atmosphere. A vertical line represents the neutral conditions, a positive slope represents stable conditions, and negative slopes indicate unstable conditions. This figure also shows the lidar observed cloud levels as hatched areas.

The clear air or background optical scattering of the marine atmosphere near the surface as measured from the ship on the days of the burns is given in Table V. The background scattering is small compared to the scattering due to the artificial cloud as can be seen from Figure 10, but is quite variable and altitude dependent since this background scattering is frequently determined by particles of surface origin which are highly altitude dependent over the first several to tens of meters.

IV PLUME MEASUREMENTS

A) General

The plumes produced during the cruise fell into one of two catagories: 1) elevated clouds or 2) surface fog banks. Both types of clouds have the potential of being useful for naval and

marine operations. Most pyrotechnic smoke production, like our pyrotechnic, has a source of heat at its point of generation and lofting of the smoke is a problem if the screen is required at the earth's surface. The marine environment in most parts of the world's ocean has a sharply defined temperature inversion within a few kilometers above the surface which acts as a cap, confining the products produced within the boundary layer. There is a possibility of exploiting this property of the marine boundary layer in order to provide an artificially produced screening canopy. Such an overhead screen would leave the horizontal lines of sight near the sea surface clear but would inhibit the overhead or slant-path lines of sight.

The property of the marine boundary layer most helpful to this application is that relative humidity usually increases with altitude inside the marine boundary layer as observed earlier in this report. Hygroscopic aerosol introduced within the boundary layer and lofted by buoyant forces toward the capping inversion will be in a higher relative humidity environment than at ship level and particles would grow to larger sizes, thus thickening a canopy cloud.

B) Canopy Clouds

The canopy cloud is one of the situations which we wished to explore during the 1983 cruise of the USNS LYNCH. This type of mesoscale phenomena could not be explored in the laboratory environment. The behaviour of the alkali halide aerosol within the confinement of the chamber is relatively easy to predict based on the previous measurements of Calspan and NRL. If the more difficult nature of the marine environment is to be included in its influence on the behaviour of the clouds of these artificial aerosols, then the complex study of boundary layer meteorology must also be introduced in the process of predicting the behaviour of these clouds.

The plumes rose from the sea surface to form an elevated cloud on the first two days of the experiment. It should be noted that these clouds become almost indistinguishable from the naturally occurring ones. It was obviously impossible to penetrate the cloud developing with the insitu shipboard instruments during these experiments. The Voltz sun photometer measurements provided a method of determining the optical depth of the cloud. As the overhead cloud passed between the shipboard observer and the sun, integrated values of the optical properties of the cloud was obtained. The sun photometer serves as the detector of a transmissometer with the sun as a light source. The optical depth τ_λ of a slab of material of thickness ℓ at a particular wavelength can according to Beer's law be defined as:

$$\tau_\lambda = \int_0^{\ell} \beta_b(x)\, dx + \int_0^{\ell} \beta_a(x)\, dx \qquad (2)$$

where $\beta_b(x)$ is a spatially dependent extinction function produced by the background aerosol and molecules and $\beta_a(x)$ is the spatially dependent extinction function produced by our artificial aerosol. A qualitative description can be gathered about the development and history of the cloud from a series of sun photometer measurements, in cooperation with the background lidar and radiosonde data, by subtracting out the background component of the optical depth at several wavelengths and making some assumptions about the geometry of the cloud.

We assumed that the artificial cloud was optically significant at relative humidities of 80% or greater and we estimated the cloud base, from the lidar returns, and the cloud top from the relative humidity records of the radiosonde flights. These data indicated cloud depths on the order of 100 meters. The true path length covered by the artificial cloud when viewed by the sun photometer, may then be calculated utilizing information about the sun's angle.

The case of the overhead canopy screen is illustrated in schematic form in figure 7. The source of aerosol is represented by a line source of length L. The total area covered is approximately equal to: L * Ws * Tb, where Ws is the mean wind speed and Tb is the elapsed time since the start and end of the burn. In real marine applications, of course, a line source is not possible, but can be approximated by a line of single unit generators operated from either ships, small boats, or helicopters. This scheme works because the temperature inversion limits the vertical diffusion, so that dissipation of the cloud due to diffusion occurs essentially on the edges.

Eddy diffusion is small at the sea surface and increases with altitude. In order for a canopy cloud to have an extended life, eddy diffusion must be reduced to near zero at the temperature inversion. This allows only the perimeter of the cloud to be acted on by diffusive forces and greatly increases the cloud lifetime.

The usual profile of relative humidity is shown in Figure 7, in which it increases with altitude. If a cloud of aerosol is produced in a drier surface layer, and then lofted by dynamic and/ or thermal forces toward the inversion, a higher ambient relative humidity is encountered promoting droplet growth.

For high relative humidities near the marine temperature inversion, the aerosol will, in most cases grow beyond the hump in the hysteresis curve shown in Figure 4. If the droplets then drift toward a lower ambient relative humidity, the size parameter of even the unstabilized droplets will remain relatively high, unless the relative humidities drop below the region of the hysteresis effect. At very high relative humidities the droplets may grow to large sizes in the region of 100% relative humidity and serve as nucleation centers for true cloud drops. These larger sizes will tend to fall out under gravity, thus modifying the size distribution.

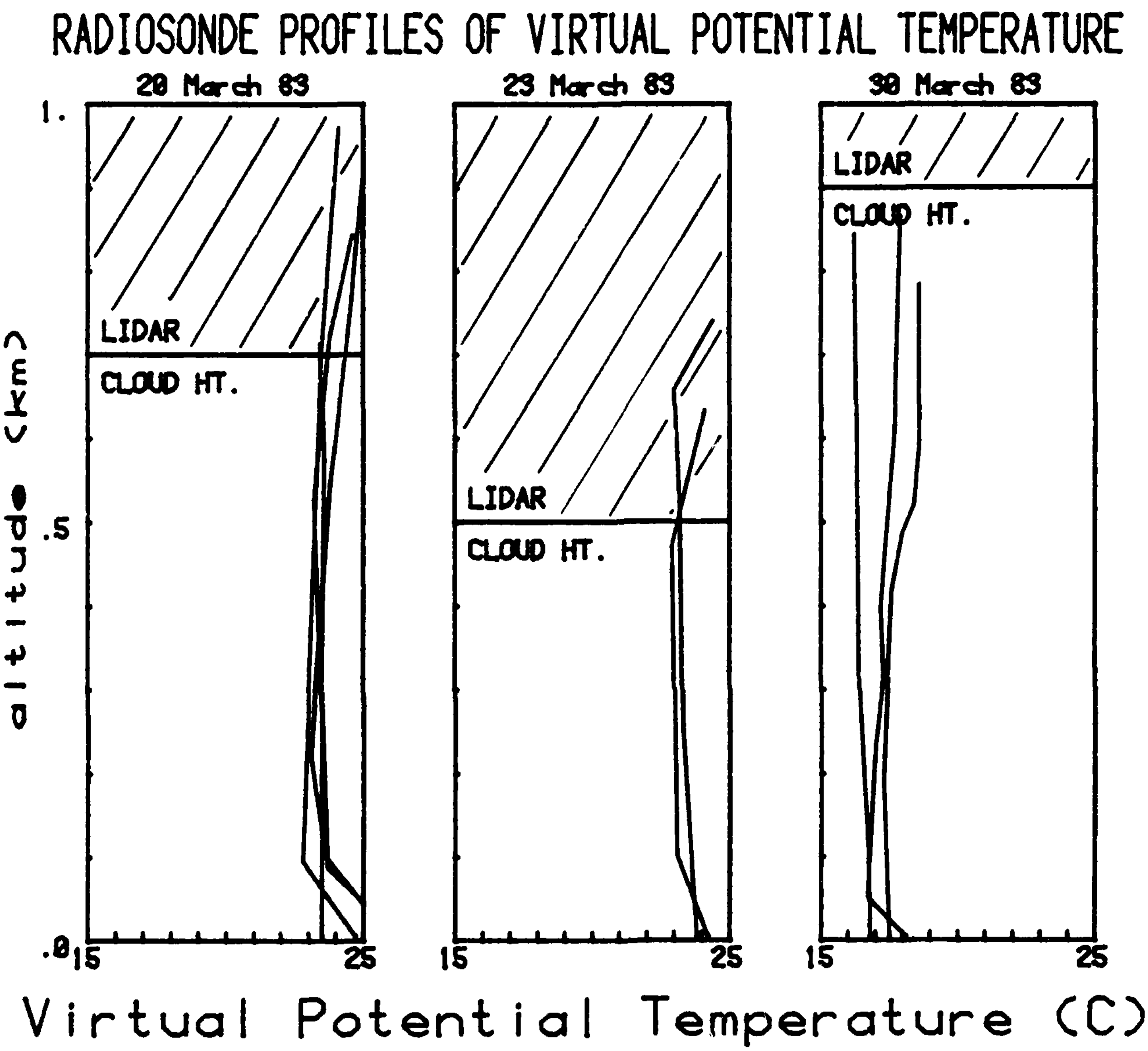

Figure 6 - Radiosonde profiles of virtual potential temperature.

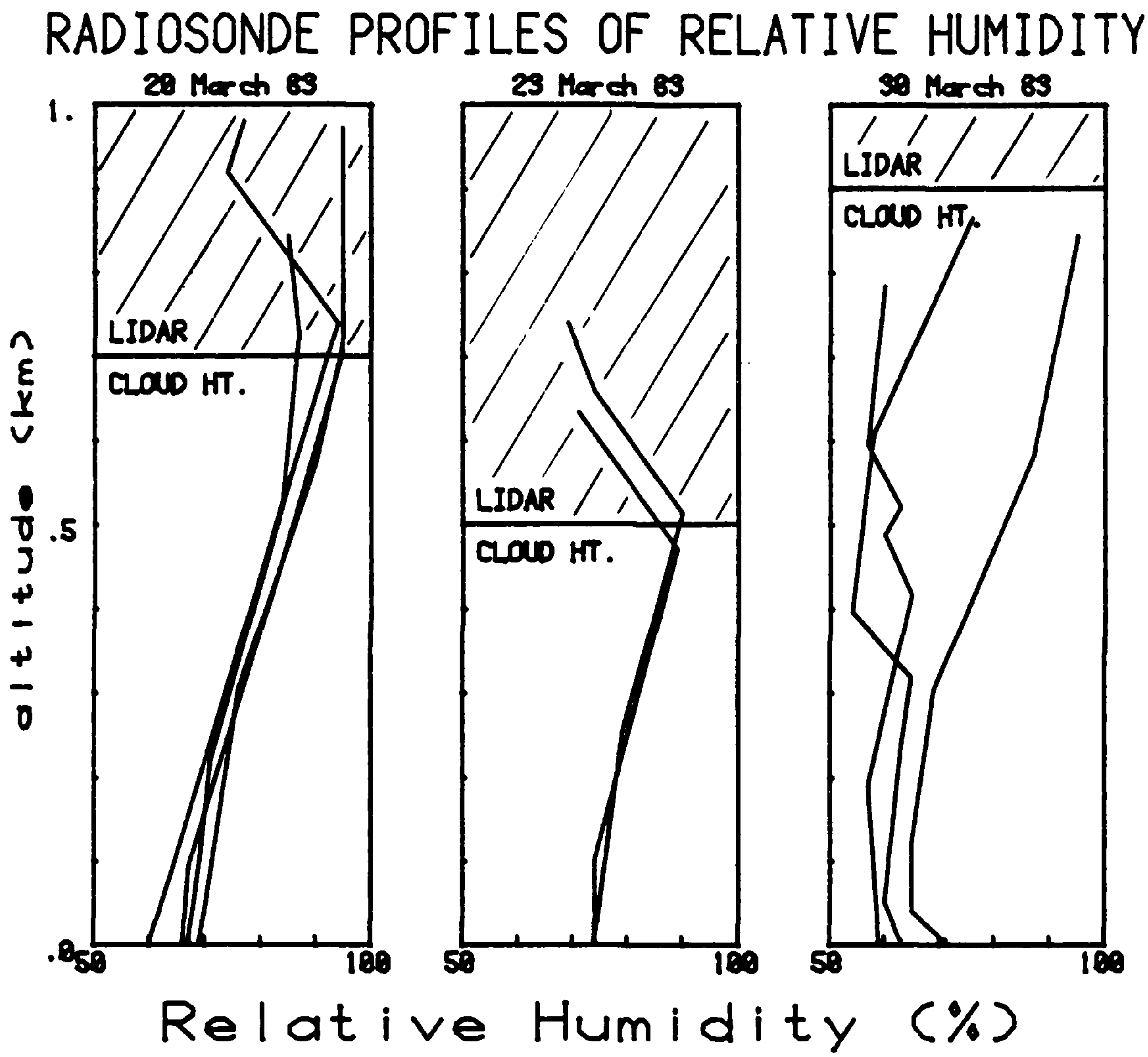

Figure 5 - Radiosonde profiles of relative humidity.

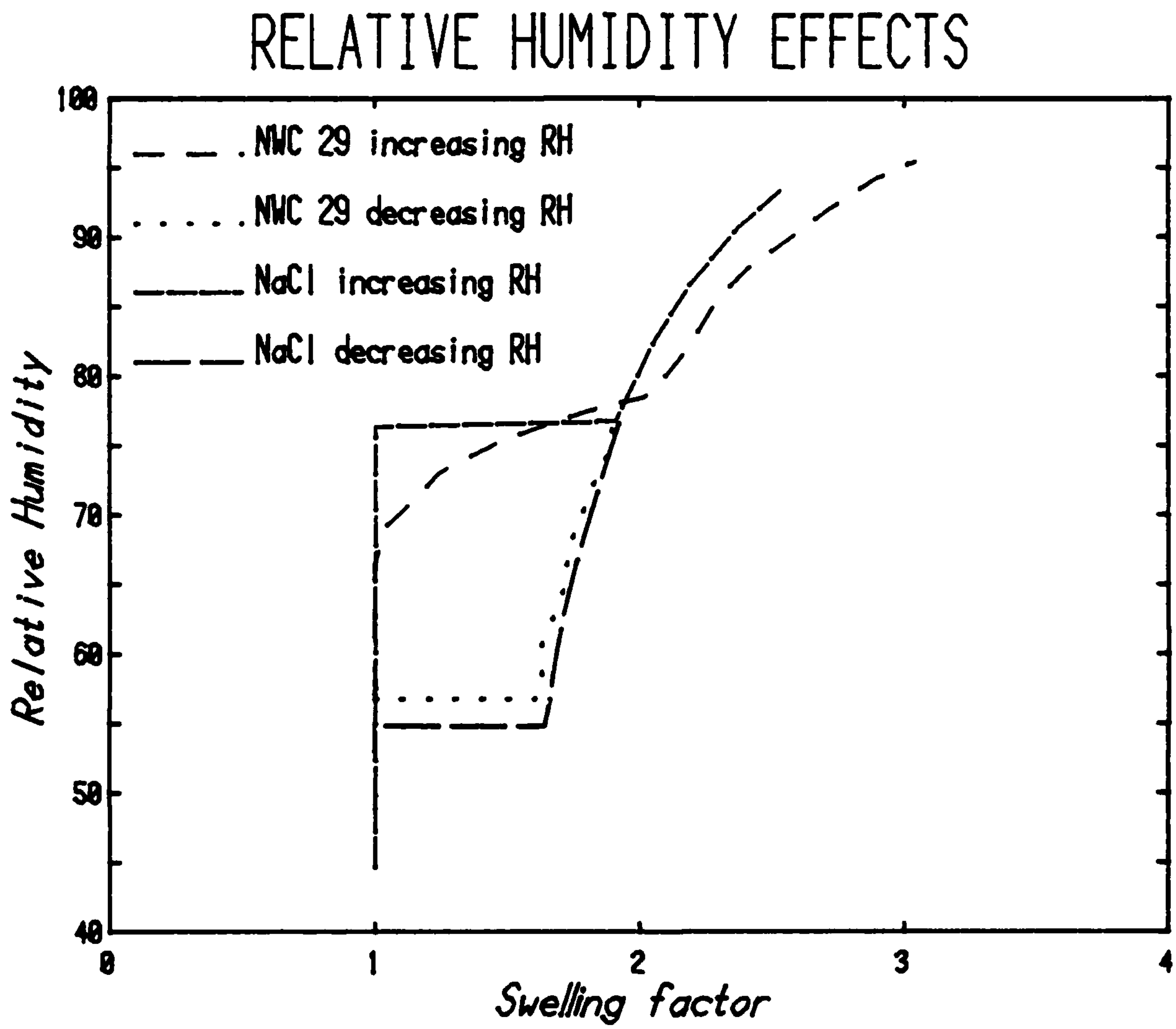

Figure 4 - Swelling factor of hygroscopic material.

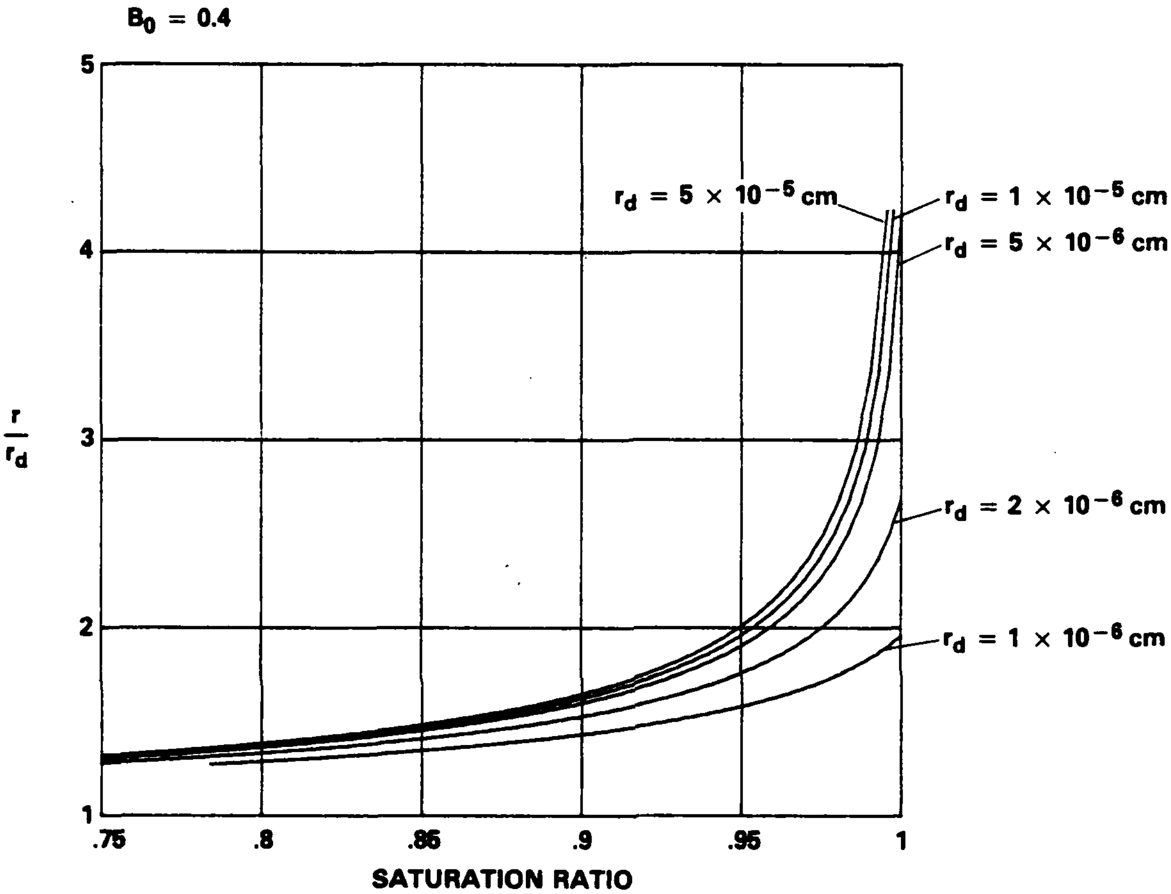

Figure 3 - The dependence of equilibrium particle size on relative humidity and dry radius for the solubility $B_0 = 0.4$.

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Figure 2 - Cloud rising from stationary burn.

1983 LYNCH CRUISE

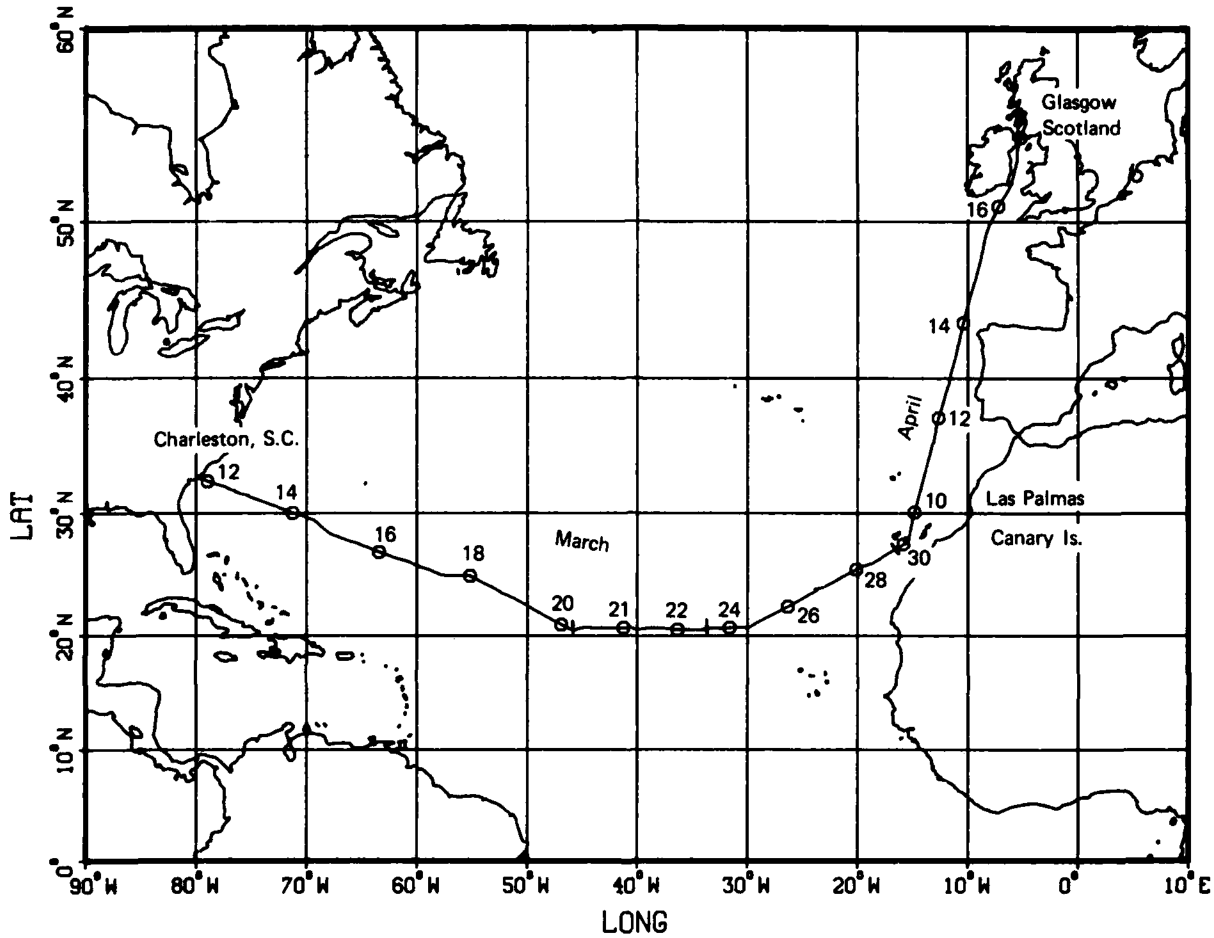

Figure 1 - Cruise track of USNS Lynch (T-AGOR-7) - NRL cruise 7-05-83 - March, April 1983.

TABLE VI

Computed Transmission Through Cloud #8
(from Size Distribution)
(250 Meters Thick Cloud)

Relative Humidity \ Wavelength (microns)	0.55	3.5	10.6
67%	16% * 6% ** 98%	68%	93%
80%	< 1%	< 1%	47%
98%	< 1%	< 1%	5%

* Measured in cloud with HSS Visiometer
** Measured in air outside of cloud with HSS

TABLE IV

Relative Humidity (%)

Instrument	Day 1	Day 2	Day 3
Sling Psychrometer (Deck)	67 ± 3	71 ± 3	62 ± 4
Dew Pointer	66 ± 2	71 ± 5	61 ± 5

TABLE V

Average Measured Scattering Coefficients
(per kilometer)
(Measured with the HSS Visiometer)

	3/20/83	3/23/83	3/30/83
HSS (visible)	0.171	0.232	0.231

TABLE II

Timing of data and events

	Test day 1	Test day 2	Test day 3
Julian Date	79	82	89
Calendar Date	20 March 1983	23 March 1983	30 March 1983
Background data Times (GMT)	0900 -- 2100	1200 -- 2000	0800 -- 2000
Burn number(#) and Ignition Time (GMT)	#1 (1250) #2 (1338) #3 (1626) #4 (1815)	#5 (1534) #6 (1634) #7 (1820)	#8 (1103) #9 (1609) #10 (1930)

TABLE III

Air Temperature (^{o}C)

Location	Height	Day 1 (Meters)	Day 2	Day 3
Mast	20	23.4 $\pm$ .3	22.9 $\pm$ .2	18.5 $\pm$ .2
Mast	14	23.4 $\pm$ .3	22.9 $\pm$ .2	18.6 $\pm$ .2
Mast	7	23.4 $\pm$ .4	23.0 $\pm$ .2	18.7 $\pm$ .2
Shelter	9	24.7 $\pm$ .6	24.4 $\pm$ .9	20.0 $\pm$ .8
Deck	6	24.2 $\pm$ .8	23.6 $\pm$ .5	19.0 $\pm$ .6
Bucket	0	24.7 $\pm$ .4	24.2 $\pm$ .5	19.4 $\pm$ .2

Table I (Continued)

15.	Beckman-Whitley Wind System	Wind Speed and Direction
16.	Satellite Navigation System (Magnavox 1102)	Ships Position, Heading and Speed
17.	Volz Sun Photometer	Light Extinction
18.	NRL Eye Safe Lidar	Inversion Height
19.	Radiosonde Equipment (PMTC Rapid Switch)	Vertical Temperature and Humidity Measurements

TABLE I

INSTRUMENTATION INSTALLED ON THE USNS LYNCH
TRANSATLANTIC/EUROPEAN COAST CRUISE -- MARCH-APRIL 1983

	Instrument	Parameter
1.	Gardner Small Particle Detector	Aerosol Concentration (> 0.0025 μm diam)
2.	Thermo Systems Model 3030 Electrical Aerosol Analyzer	Aerosol Size Distribution (0.01 to 0.56 μm diam)
3.	Royco Model 225 Particle Counter	Aerosol Size Distribution (0.56 to 5.0 μm diam)
4.	NRL Mobility Analyzer	Particle Size Distribution
5.	PMS Aerosol Spectrometer (Model asasp - 300)	Particle Size Distribution
6.	Calspan Droplet Sampler (Gelatin Replication)	Drop Size Distribution (3-100 μm diam)
7.	QAM Cascade Impactors Piezo Electric (California Measurements, Inc.)	Particle Size Distribution
8.	Casella Cascade Impactors (> 0.05 m diam)	Aerodynamic Aerosol Size Distribution for SEM Analysis
9.	Aerosol Filter Sampler	Mass Load and Chemical Analysis
10.	MRI Integrating Nephelometer (Model 2050)	Scattering Coefficient (.1 - 100 x 10^{-4} m^{-1})
11.	HSS Visiometer (Model VR301)	
12.	Foxboro Temperature System (4 Sensors)	Sea Surface and Air Temperatures
13.	Sling Psychrometer	Wet and Dry Bulb Temperatures
14.	Temperature/Dewpoint System Cambridge Systems, Inc. (Model 110 SM)	Temperature and Dewpoint

(1 drum of pyrotechnic) the optical depth of the screen is reduced by about one half after 30 minutes under the diffusion conditions present in the marine boundary layer when this test was made. This reduction in optical depth is primarily due to dispersal rather than particle fallout, so that as the optical depth lessens, the obscured area increases. It is noteworthy to mention that background optical thicknesses are typically in the range .05 - .15. The degree of effectiveness most certainly depends on the prevailing meteorological conditions, particularly wind speed and relative humidity. Also important is the deployment technique used which determines whether surface or canopy clouds are produced. The height of the inversion layer and accompanying winds will affect the development and persistence of canopy cloud cover.

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within the plume is shown in Figure 11 where the crosses represent data points, and the solid line is a fit of the data to the sum of two lognormal distributions.

The transmission through a cloud with the particle size distribution shown in Figure 11 can be computed for several wavelengths using Mie theory, and the expected transmission at higher ambient relative humidities can also be computed using theoretical growth relationships. The results of these computations are shown in Table VI for the wavelengths of 0.55, 3.5 and 10.6 microns. The transmission values are listed for three relative humidities of 67% (measured value during the cloud penetration period), 80% and 98%. The transmission as determined independently from the HSS measurements made at 0.55 microns and at 67% relative humidity during plume penetration was 6% with a background transmission outside the cloud of > 98%. The transmission as calculated from the particle size distribution and the same set of meteorological parameters was 16%, indicating that the calculations tend to predict more transmission than the direct measurements. If the burn had been under conditions of a more typical maritime relative humidity such as 80%, then the measured transmission would have been much less, and at 98% relative humidity as might be encountered near the top of the boundary layer the transmission would be down to 5% even at wavelengths out to 10.6 microns.

V DISCUSSION

The behavior of plumes within the marine boundary layer is statistical in nature and the process describing a particular plume is unpredictable with our present knowledge. The interaction between atmospheric turbulence and the breaking up of the developed plume and subsequent dispersal is also beyond the scope of this report, being a larger scale phenomenon. Therefore, the measurements which are reported here (i. e., optical depth and transmission) must not be considered to be absolute in nature, and it must be understood that they represent the effects of only a single drum of pyrotechnic per experiment operating under a specific set of meteorological conditions. The experiments were large scale in comparison with those performed in the laboratory, but small scale when compared with an actual deployment situation. In order to obtain a desired obscuration for a given area over a certain time interval, the problem of how much pyrotechnic to burn, and where, when and how to do it, must be solved.

VI CONCLUSION

Alkali halide aerosol can provide an effective screen for visible and near infrared wavelengths. As is shown in Figure 8, maximum screening with an optical depth of 2 is obtained within the first 15 minutes of aerosol deployment and for a point source

Figure 8 shows a plot of the optical thickness at various wavelengths plotted as function of time for the small artificial clouds of 23 March 1983. Although it was not possible to make the measurements as close together as we would have liked, there is adequate data to determine the general characteristics of the cloud. Of particular interest is the systematic delay in response of a cloud of hygroscopic aerosol exposed to both a rapid increase in ambient relative humidity and a persistent long term diffusive action. As the population of aerosols was lofted toward the marine inversion, the individual particles start to add water and increase their size. This in turn causes increased scattering for the population. As they are starting from very small sizes, they scatter the smallest wavelengths first but as they continue growing the large particles which scatter longer wavelengths become more active, while the shorter wavelength scatterers which have already reached their peak decrease.

C) Surface Clouds

Because of the relatively unstable conditions much difficulty was experienced in trying to both produce a surface cloud and then penetrate the plume with the slow moving ship. Conditions were acceptable on the third experiment day, where the best penetration data was obtained. On day two, there was a mixed effect in which some penetration of the plume took place along with some elevated cloud effects. Figure 9 is a schematic of the surface fog-generation technique.

The surface cloud offers the best opportunity to study the microphysics of the screening cloud because the ship based sensors could penetrate the cloud and record insitu the effects within the screen.

The chief operational deficiency was in using the same slow-moving ship to both generate and sample the aerosol. A minimum relative wind speed had to be exceeded in order to "lay-out" a surface cloud, otherwise the cloud would loft (due to the updraft caused by the pyrotechnic) and elude our instrumentation. By the time the ship had turned about to chase it's cloud, it had often broken into several remnants near the surface and only a few minutes remained to perform the sampling. When this is coupled with the time constant in most of the instrumentation, which is on the order of 30 seconds, it is surprising the data shows much agreement at all. Some instrumentation such as the differential mobility analyzer requires at least 15 minutes of sampling to provide a size distribution and thus could be used only for the background measurements shown in Table V.

The scattering data taken with the HSS visiometer during transit of Plume 8 is shown in Figure 10. The visibility was reduced for a period of about 12 minutes and the visibility decreased by over two orders of magnitude in the densest part of the cloud, with an order of magnitude or more reduction in visibility lasting about 7 minutes. A particle size distribution

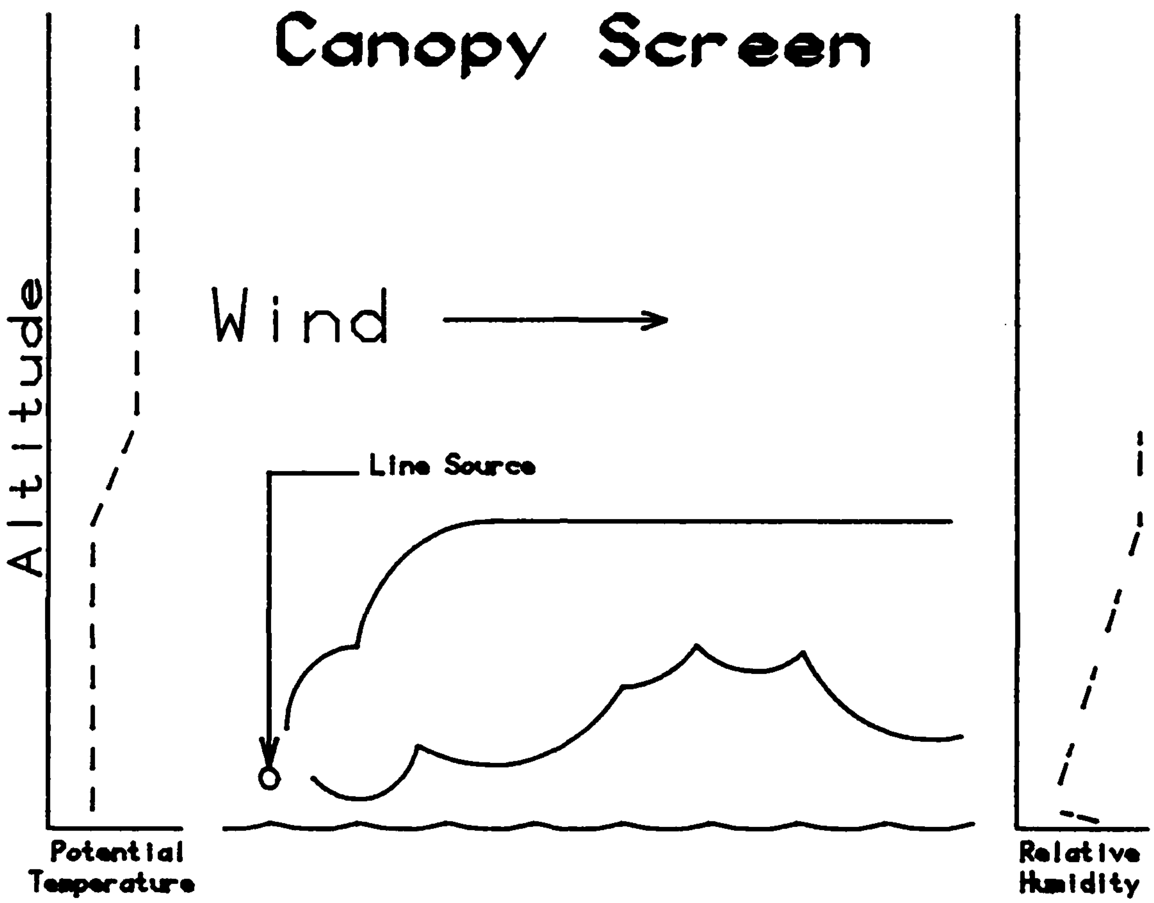

Figure 7 - Idealized production of a canopy screen within the maritime boundary layer.

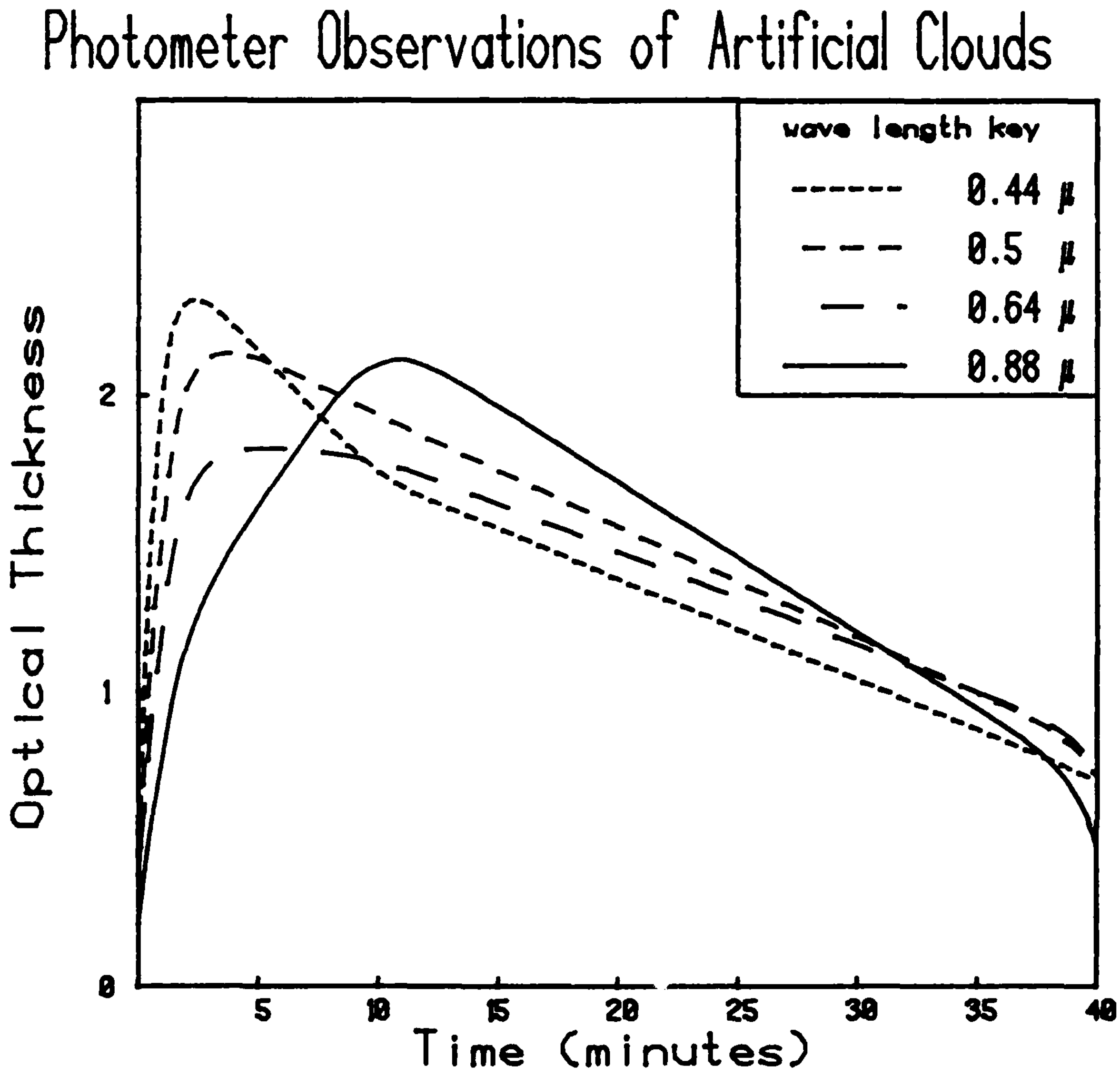

Figure 8 - Sun photometer readings of optical thickness of artificially produced canopy clouds produced over mid ocean, (USNS LYNCH - 1983).

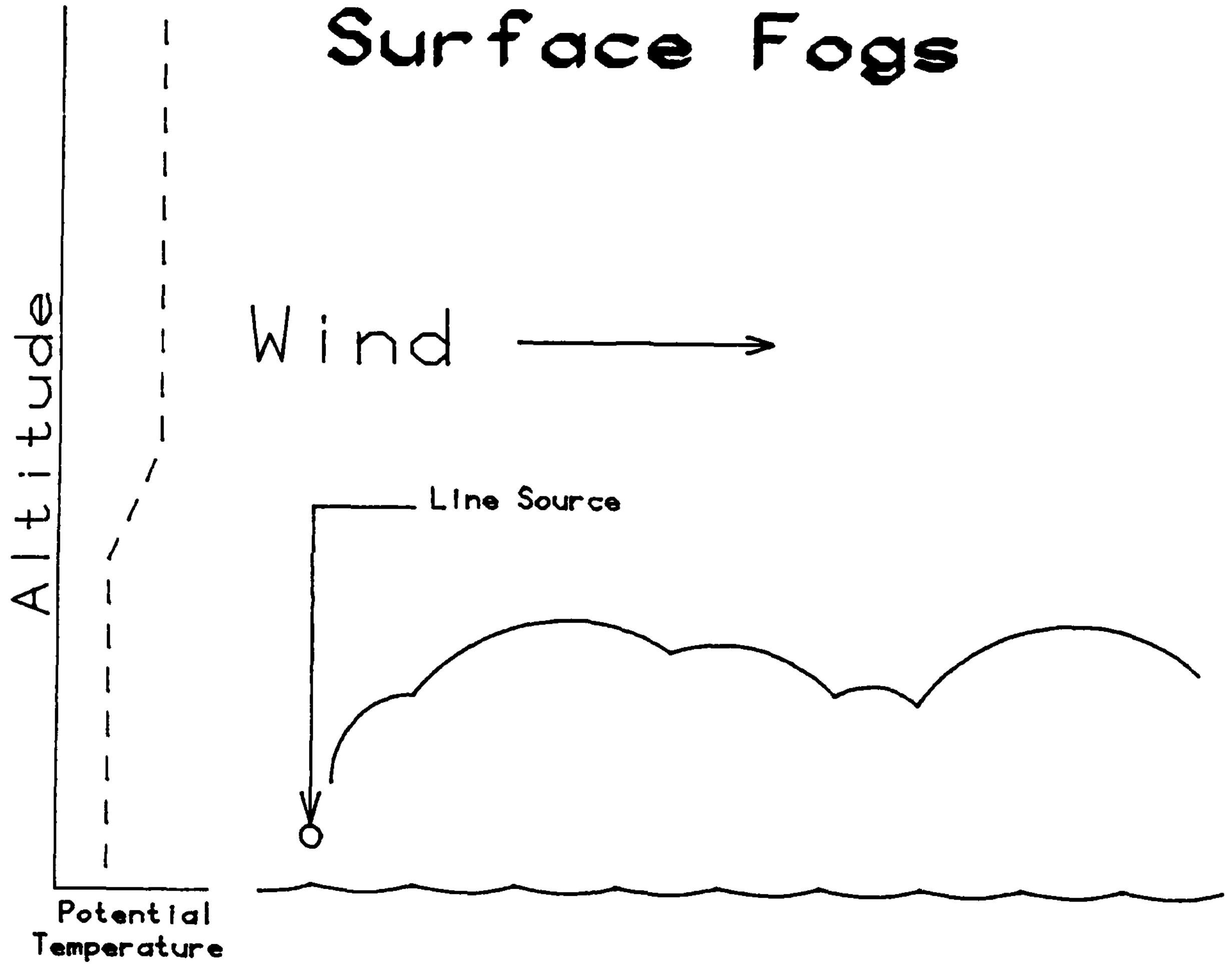

Figure 9 - Idealized production of a surface screen.

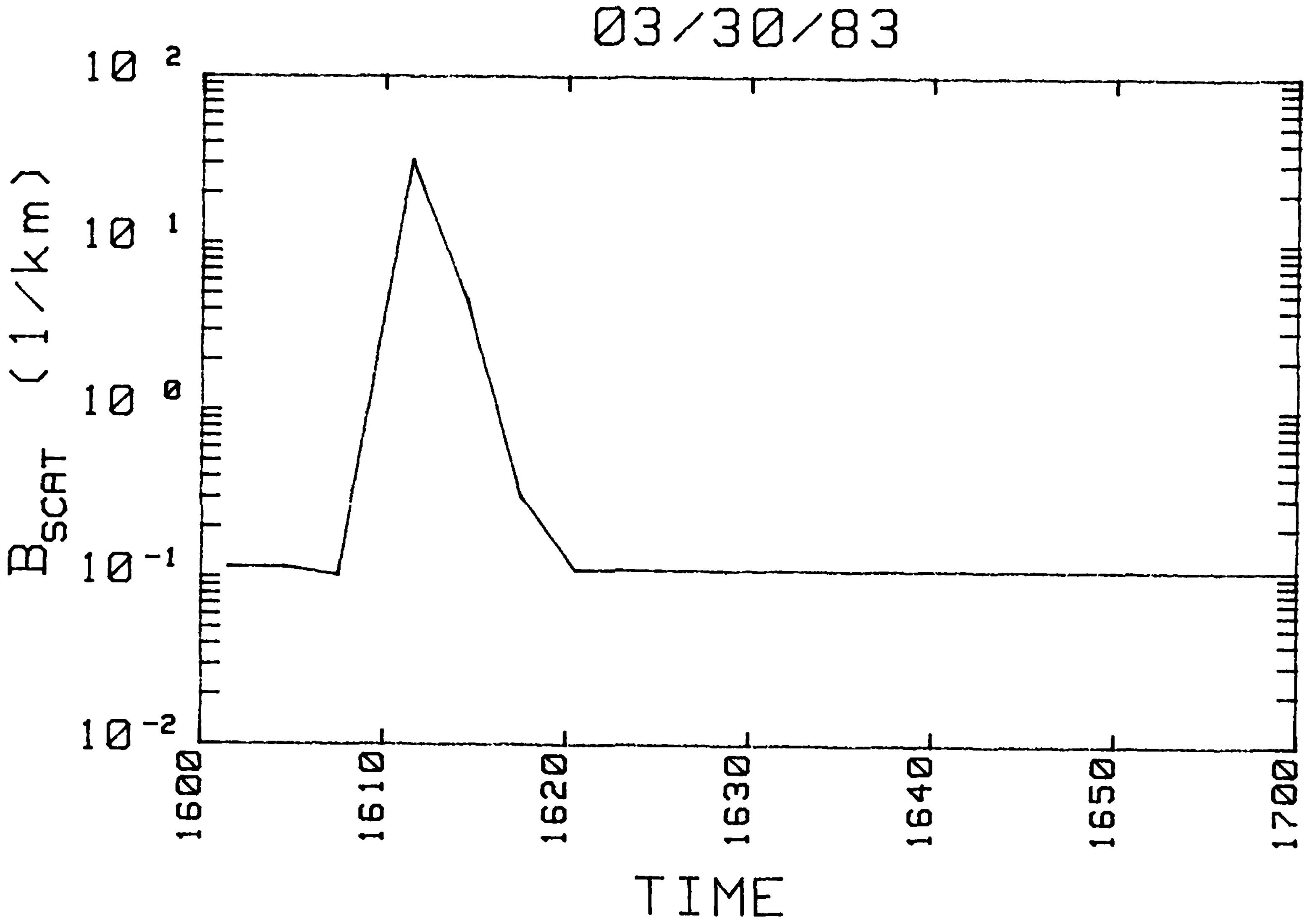

Figure 10 - Smoothed plot of backscattering at 0.55 microns during transit of cloud #8.

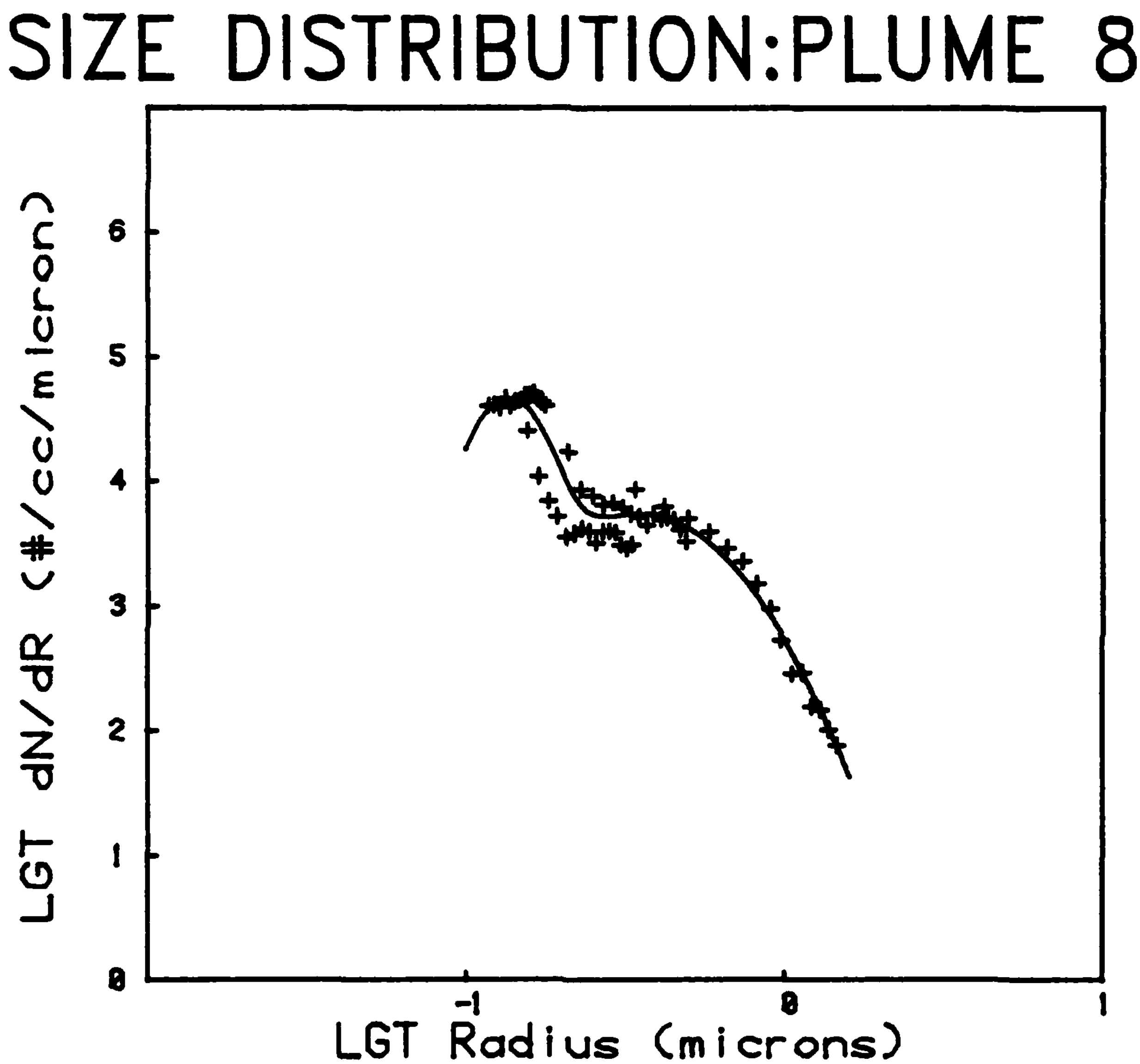

Figure 11 - Size distributions measured in cloud #8. Crosses are data points and line is best fit to sum of two lognormal curves.

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